Dual-Functional Electrically Small Huygens Antenna System

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***Abstract* – A dual-functional electrically small Huygens antenna system is introduced for wireless power transfer (WPT) and communication applications at 915 MHz. This dual-functional system is facilitated by using two orthogonally-oriented electrically small Huygens linearly polarized (HLP) dipole subsystems. Each HLP antenna consists of two metamaterial-inspired near field resonant parasitic (NFRP) elements, i.e., the capacitive loaded loop (CLL) and the Egyptian axe dipole (EAD). A rectifier circuit is integrated with one of the HLP antennas to facilitate its function as a rectenna for WPT applications. The other HLP antenna serves the communication applications. Due to the large isolation (> 30 dB) between these two HLP subsystems, their functionalities are independent. A successfully fabricated and measured prototype demonstrates that this highly-integrated dual-functional antenna system has excellent performance characteristics. It is electrically-small (*ka* < 0.77) and produces unidirectional Huygens (cardioid) broadside realized gain patterns with broad beamwidths. It has a high AC to DC conversion efficiency. The antenna system is an excellent, practical candidate for wireless Internet-of-Things (IoT) applications.**

***Index Terms* — Cardioid patterns, electrically small antennas, Huygens dipole antennas, near field resonant parasitic (NFRP) antennas, wireless power transfer (WPT).**

1. Introduction

Wireless Internet-of-Things (IoT) applications will be ubiquitous in the near future. Wireless power transfer (WPT) and communication functions are two of their essential features. With the need to power the rapidly increasing numbers of IoT devices on a mobile platform, powering them wirelessly has become another major impactful trend. Moreover, IoT devices must be equipped to handle some form of wireless Device-to-Device (D2D) communications to exchange information [1]. Furthermore, it would highly desirable to have both functionalities together in a compact system [2]. However, no electrically small wireless system supporting both WPT and communication functions has been reported to date.

This paper presents an innovative design in which the dual-functions, WPT and communications, are integrated seamlessly together into an electrically small antenna system. This system is realized with two orthogonally-oriented electrically small Huygens linearly-polarized (HLP) dipole radiators [3]–[5]. A rectifier circuit is combined with one HLP element for the WPT function. The second HLP element facilitates the communication function. The whole antenna system is electrically small (*ka* < 0.77) and low profile. Despite its compact footprint, the system exhibits excellent radiation performance characteristics. It produces unidirectional Huygens (cardioid) broadside realized gain patterns with broad beamwidths and high directivities (4.5 dBi). Large isolation (> 30 dB) between both functions is realized. Moreover, unlike the reported rectifier designs in [6]–[9] that adopt a microstrip line feed structure, our design employs co-planar stripline (CPS) techniques. The entire size of the rectifier is compact and yields a high AC to DC conversion efficiency, 78%. This dual-functional antenna system is the excellent, practical candidate for emerging wireless IoT applications including advanced wireless sensor networks, body-centric wireless communication systems (BWCS), and unmanned aerial vehicles (UAVs) [10], [11].

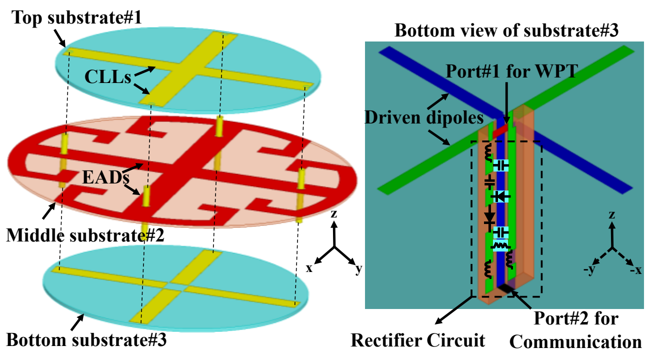

Fig. 1. Configuration (isometric views) of the dual-functional electrically small Huygens antenna system

2. Antenna Design

The configuration of the antenna system is illustrated in Fig. 1. It consists of three PCB substrate layers and four metamaterial-inspired near field resonant parasitic (NFRP) elements: two capacitive loaded loops (CLLs) and two Egyptian axe dipoles (EADs). The two CLLs are orthogonally oriented. Their segments are printed on the tops of substrate#1 and substrate#3 and are connected via the four copper posts. The EAD radiators are printed orthogonal to each other on the top of the middle substrate#2. On the bottom side of substrate#3, two short driven dipoles are printed in a cross shape. A fourth substrate is attached below and orthogonal to the assembled three layers. The rectifier circuit is placed on it and connected with a CPS feedline to port#1 for the WPT HLP and another CPS feedline on it is connected to input port#2 for the communications HLP.

3. System Performance

The simulated radiation performance of both HLP antenna subsystems is presented in Figs. 2 and 3. With the orthogonality of the two HLP subsystems, the isolation between their two ports is larger than 30 dB. As a consequence, the VSWR values and realized gain patterns for both the WPT and communication subsystems are nearly identical. The VSWR results in Fig. 2 indicate that both HLP antennas are resonating at the target frequency, 915 MHz. The VSWR values are approximately 1.0 at this frequency for both subsystems. Their high peak directivities, 4.5 dBi, are also achieved at 915 MHz. As shown in Fig. 3, the corresponding very good cardioid-shaped normalized realized gain patterns have quite broad 3dB beamwidths (±65°) in both the $\varphi = 0°$ and $\varphi = 90°$ vertical planes.

As an essential part of the WPT function, the design of the rectifier circuit is shown in Figs. 1 and 2(b). A CPS feedline is adopted to integrate it with its HLP subsystem. This rectifier circuit is composed of two HSMS286 Schottky diodes; one inductor L; three capacitors: C_1, C_2 and C_3; and a resistor R_L. Impedance matching is facilitated by L and C_1. The DC block and charge storage for the vertical dipole is provided by C_2. Ripples in the DC voltage output are minimized by the high pass filter formed with C_3. The load resistor R_L is tied to the output port. Fig. 2(b) shows the measured and simulated DC voltage output of the rectifier circuit as functions of the input power when the values of the components are: L = 27 nH; C_1 = 0.3 pF; C_2 = 4.7 pF; C_3 = 100 pF and R_L = 10 KΩ. It is clear that the measured DC voltage outputs agree well with their simulated values. The AC to DC conversion efficiency is larger than 50% for input powers from 1 to 11 dBm. A peak value, 78%, is achieved for 8 dBm. It is noted that the peak and saturated DC outputs are 7.8 V which is a value higher than the simulated 6.7 V. This discrepancy arises from the differences between the actual components and their models in Agilent's Advanced Design System (ADS) software.

4. Conclusion

An innovative, compact, dual-functional electrically small antenna system for WPT and communication applications has been presented. Simulated radiation performance and measured results of the rectifier circuits are reported. The full system measurements will be reported at the conference.

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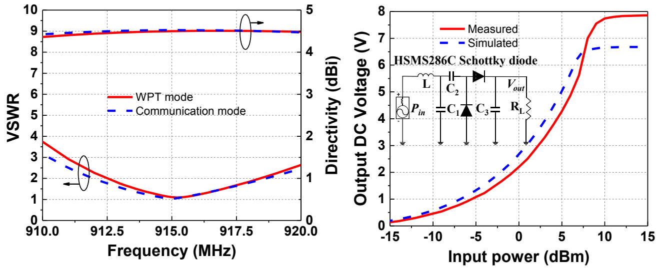
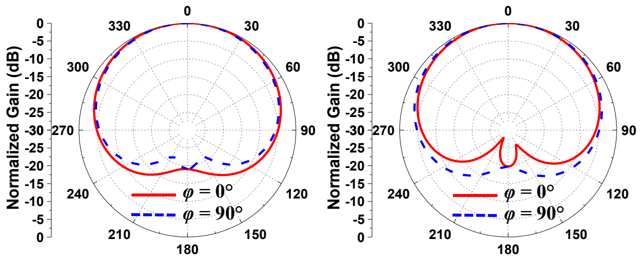


(a) (b)

Fig. 2. (a) Simulated VSWR and directivity of the HLP subsystem. (b) Measured and simulated output DC voltage of the rectifier circuit as functions of the input power.



(a) WPT Mode (b) Communication mode

Fig. 3. Simulated normalized realized gain patterns at 915 MHz for both functioning modes.

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